Response to Comments of Reviewer #1

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Title: Global assessment of climatic responses to the ozone-vegetation interactions

The authors are grateful to the editor and reviewers for their time and energy in providing helpful comments that have improved the manuscript. In this document, we describe how we have addressed the reviewer's comments. Referee comments are shown in black italics and author responses are shown in blue regular text. A manuscript with tracking changes is attached separately.

Anonymous referee #1:

General comment

The paper presents a comprehensive array of feedbacks on climate variables resulting from O_3 -vegetation interaction during boreal summertime of the period 2005-2014. Utilizing the climate-vegetation-chemistry coupled ModelE2-YIBs model, this study compares a simulation assuming no damage to vegetation, with another incorporating high O_3 sensitivity. While some parts of methods and results need clarifications, some corrections, and further editing, the topic of this study is suitable for ACP and enriches the already existing literature.

Response:

Thank you for your positive evaluations.

Abstract

I think the abstract is good, presenting the scope of the paper concisely. I realize it's a matter of personal taste, but I'd only suggest a less "number-intensive" report of the results in this section. Furthermore, "2010s" appears for the first time here, indicating the "2005-2014" period, while, commonly, it indicates the 2010-2019 period. If possible, I would suggest finding a different label for this time window throughout the article.

Response:

Thank you for your suggestion. We chose a new label "the present day" for the "2005-2014" time window and limited the use of numbers as follows:

"The most significant responses are found in the eastern U.S. and eastern China, where surface air temperature increases by +0.33±0.87 °C and +0.56±0.38 °C, respectively. These temperature rises are accompanied by decreased latent heat and increased sensible heat in both regions." (Lines 19-22)

"Using a climate-vegetation-chemistry coupled model (the NASA GISS ModelE2 coupled with Yale Interactive terrestrial Biosphere, or ModelE2-YIBs), we assess the global climatic responses to O_3-vegetation interactions during boreal summer of the present day (2005-2014)." (Lines 15-18)

Introduction

In my opinion, the introduction provides the essential information to contextualize the paper, listing an adequately ample array of examples regarding ozone effects on vegetation and the possible types of feedback. Anyway, I believe it would be helpful to provide more details for the readers that are less familiar with this specific subject, and to improve the style for enhanced coherence.

Response:

Thank you for your rewarding advice.

Line 45: I believe that flux-based measurements are also statistical, at least to some extent, so I would avoid qualifying exposure-based indexes this way – I suggest either substituting or removing the adjective.

Response:

Thank you for your suggestions. In the revised paper, we removed this sentence and added descriptions of more exposure-based and flux-based indexes for the better clarity: "Several exposure-based indexes such as accumulated hourly O_3 concentrations over a threshold of 40 ppb (AOT40) and sum of all hourly average concentrations (SUM00) are used to assess O_3-induced vegetation damage (Fuhrer et al., 1997; Paoletti et al., 2007). In addition, the flux-related POD_y method (phytotoxic O_3 dose above a threshold flux of y) is also widely applied to consider the dynamic adjustment of stomatal conductance (Buker et al., 2015; Sicard et al., 2016)." (Lines 44-50)

Line 45-46: it might be good to specify what the "dynamic adjustment of vegetation physiological processes" depends on.

Response:

Thank you for the suggestion. Here, the 'vegetation physiological processes' are mainly referred to 'stomatal conductance'. We modified the sentences as follow:

"… the flux-related POD_y method (phytotoxic O_3 dose above a threshold flux of y) is also widely applied to consider the dynamic adjustment of stomatal conductance (Buker et al., 2015; Sicard et al., 2016)." (Lines 47-50)

Line 51: I'm not sure "inconsistent" is the appropriate adjective in this case. I'd reframe this in a different way.

Response:

We changed the word to "decoupled", and the revised sentence is as follow:

"In contrast, Lombardozzi et al. (2012) estimated the decoupled reductions in plant photosynthesis and stomatal conductance using different response relationships to the cumulative O_3 stomatal uptake." (Lines 55-57)

Line 63: "but" introduces a contrast, whereas "consistent but stronger" seems to convey an idea of enhancement. I'd suggest choosing a different wording. Throughout the paper, this adverb was used in the same way (i.e. introducing contrast without need) and I believe that substituting it with other words, or reframing these sentences could enhance clarity.

Response:

Thank you for pointing out the logical grammar issues in our writing. We adjusted this sentence as follows:

"As a comparison, Sadiq et al. (2017) found consistently stronger feedback on O3 concentrations in these polluted regions using the scheme of Lombardozzi et al (2012) embedded in the Community Earth System Model (CESM)." (Lines 67-70)

Line 65-67: The sentence "Inclusion of O_3-vegetation… surface O_3" feels disconnected from the rest on the text and, just by reading it, it is unclear if it is a consequence of what has been said earlier, if it's a claim lacking a reference, or if it's introducing the next sentence (in which case I'd suggest to improve the whole 65-72 lines).

Response:

We revised the sentence so that it clearly introduces the next content:

"Moreover, the inclusion of online O_3-vegetation interactions in numerical models will also result in a greater loss of simulated land carbon assimilation due to the feedbacks of both ecosystems and surface O_3. This is attributable to several factors." (Lines 70-73)

Line 73-74: I believe "In addition to… between land and atmosphere" would be a direct consequence to ozone affecting stomatal conductance and I would mention this to improve logical coherence.

Response:

We revised the mentioned sentence to make it more logical:

"In addition to affecting surface O_3, the O_3-vegetation interaction can also alter the water and energy exchange between land and atmosphere through the modulation of stomatal conductance." (Lines 80-82)

Line 92: "aggregated" instead of "aggregate"? Anyway, the 91-93 sentence "which calculated… functional types" could be improved in clarity.

Response:

We revised the sentence as follow:

"This fully coupled framework was implemented with the semi-mechanistic O_3 damage scheme proposed by Sitch et al. (2007), which calculated aggregated O_3 damage to photosynthesis based on varied sensitivities to instantaneous stomatal O_3 uptake across eight plant functional types (PFTs)." (Lines 97-100)

Method

This section highlights adequately the general structure and workflow of the study. While it outlines the essential methods, I believe it would benefit with more details. Please add unit of measure when introducing some variable.

Response:

Thank you for your evaluation. We added unit of variables in the revised section following the suggestion.

To my understanding, surface O_3 within ESMs refers to the O_3 concentrations at the lowest model level, which might correspond to about 15-25 m above the ground, or even more depending on the vertical resolution. Do you think that this affects the O_3 evaluation part, since measuring stations are typically at a lower height (2-3 m above the ground)? In any case, I suggest providing more details about this matter, in the section 2.1 and/or in the section 2.4.

Response:

First, the vertical resolution of model affects near-surface O_3 simulation, as demonstrated by Shindell et al. (2003), who reduced bias in low-level ozone simulations from 31% to 8% by improving the model from 9 to 23 layers. Increasing the vertical resolution to 40 layers in our current model (Schmidt et al., 2014) significantly improves dry deposition simulation, consequently enhancing the accuracy of the model in simulating surface O_3 concentrations. Second, we think that the specific height difference of surface O_3 between the observations and the numerical model may affect the evaluation results to some extent, as O_3 concentrations near the surface vary with height (Fig. R1).

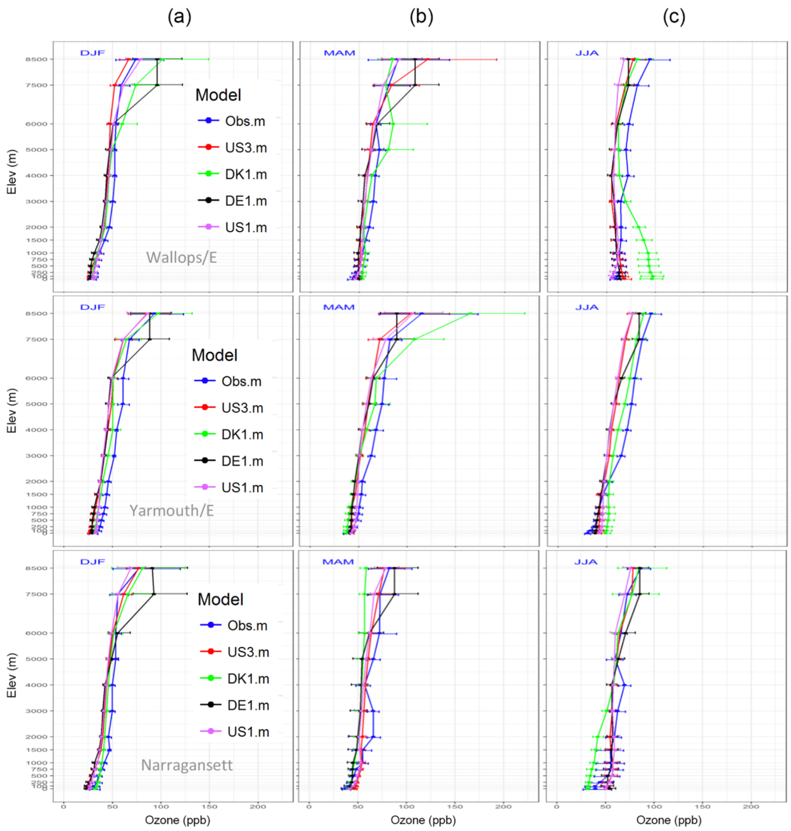


Figure R1. Seasonal vertical profiles of ozone mixing ratios for 2010 (a: winter; b: spring; c: summer), for stations located in the East America. The horizontal lines indicate the 95 % bootstrapped confidence interval for each vertical layer. (figure from Astitha, M., Kioutsioukis, I., Fisseha, G. A., Bianconi, R., Bieser, J., Christensen, J. H., Cooper, O. R., Galmarini, S., Hogrefe, C., Im, U., Johnson, B., Liu, P., Nopmongcol, U., Petropavlovskikh, I., Solazzo, E., Tarasick, D. W., and Yarwood, G.: Seasonal ozone vertical profiles over North America using the AQMEII3 group of air quality models: model inter-comparison and stratospheric intrusions, Atmos. Chem. Phys., 18, 13925–13945, https://doi.org/10.5194/acp-18-13925-2018, 2018.)

However, this bias will not affect the validation of the capacity of model for capturing the characteristics of the spatial distribution of the surface O_3. Moreover, daytime is the period when O_3-vegetation interactions usually occur. According to Zhang et al. (1999), the observed O_3 concentrations at different heights near the ground in summer do not vary much during the day (Fig. R2).

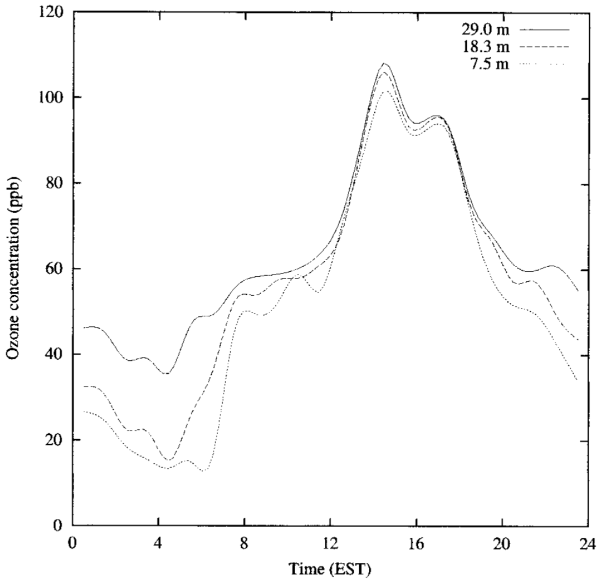


Figure R2. O_3 concentrations measured at the 29.0-m, 18.3-m, and 7.5-m levels above ground at the Harvard Forest on 10 August 1995 (figure from Zhang, J. and Rao, S. T.: The role of vertical mixing in the temporal evolution of ground- level ozone concentrations, J. Appl. Meteor. Climatol., 38, 1674-1691, https://doi.org/10.1175/1520-0450(1999)038<1674:TROVMI>2.0.CO;2, 1999.).

Finally, the gridded O_3 observational datasets utilized in this study are sourced from research aiming at providing datasets for model evaluation. For this, we provided more explanation in Section 2.4:

"The worldwide observations of the maximum daily 8-hour average O_3 (MDA8 O_3) concentrations were mainly collected from three regional networks: Air Quality Monitoring Network operated by Ministry of Ecology and Environment (AQMN-MEE) in China, the Clean Air Status and Trends Network (CASTNET) in the U.S., and the European Monitoring and Evaluation Programme (EMEP) in Europe. Observations used for validation beyond China, sourced from Sofen et al. (2016), are averaged over the period 2005-2014. This dataset encompasses 7288 station records worldwide and excludes the uncertainty associated with high mountain-top sites." (Lines 198-206)

2.1 Model descriptions

This section should mention the temporal resolution for the model.

Response:

Added as suggested.

"Both the physical and chemical processes are calculated every 0.5 h and the radiation module is called every 2.5 h." (Lines 112-114)

Line 115-116: It might be a good idea to offer more details about , , and

Response:

It seems that some information is missing in the comment. We guess that you suggest us to add some descriptions of modeling schemes for both photosynthesis and stomatal conductance. We revised this part as follows:

"Here, the total leaf photosynthesis, denoted as A_{tot} (unit: μmol m^{-2} [leaf] s^{-1}), is calculated considering both C_3 (Collatz et al., 1991) and C_4 plants (Collatz et al., 1992). The A_{tot} is derived from the minimum value of the constraints. The ribulose-1,5-bisphosphate carboxylase (Rubisco) limited rate of carboxylation is J_c:

$$J_c = \begin{cases} V_{cmax}\left(\dfrac{c_i - \Gamma_*}{c_i + K_c(1 + O_i/K_o)}\right) & \text{for } C_3 \text{ plant} \\ V_{cmax} & \text{for } C_4 \text{ plant} \end{cases} \quad (2)$$

The carboxylation rate restricted by the availability of light is J_e:

$$J_e = \begin{cases} a_{leaf} \times PAR \times \alpha \times \left(\dfrac{c_i - \Gamma_*}{c_i + 2\Gamma_*}\right) & \text{for } C_3 \text{ plant} \\ a_{leaf} \times PAR \times \alpha & \text{for } C_4 \text{ plant} \end{cases} \quad (3)$$

The export-limited rate for C_3 plants and the phosphoenolpyruvate carboxylase (PEPC) limited rate of carboxylation for C_4 plants are represented by J_s:

$$J_s = \begin{cases} 0.5\, V_{cmax} & \text{for } C_3 \text{ plant} \\ K_s \times V_{cmax} \times \dfrac{c_i}{P_{atm}} & \text{for } C_4 \text{ plant} \end{cases} \quad (4)$$

In these functions, V_{cmax} (μmol m^{-2} s^{-1}) is the maximum carboxylation capacity. c_i and O_i (Pa) represent the internal leaf CO_2 and oxygen partial pressure. Γ_* (Pa) denotes the CO_2 compensation point, while K_c and K_o (Pa) are Michaelis–Menten constants for the carboxylation and oxygenation of Rubisco, respectively. The parameters Γ_*, K_c, and K_o vary with temperature based on the sensitivity of the vegetation to temperature (Q_{10} coefficient). PAR (μmol m^{-2} s^{-1}) is the absorbed photosynthetically active radiation,

a_{leaf} is leaf-specific light absorbance that considers sunlit and shaded leaves, and α is quantum efficiency. P_{atm} (Pa) represents the ambient pressure. K_s is set to 4000 as a constant following Oleson et al. (2010), to limit photosynthesis of C_4 plants get saturated at lower CO_2 concentrations." (Lines 123-139)

2.2 The O_3-Vegetation damage scheme

Line 134: Calculation for should be detailed further.

Line 135: would need a reference.

Response:

We further clarified this part as follows:

"

$$F_{O3} = \frac{[O_3]}{R_a + [\frac{k_{O3}}{g_{sd}}]}, \quad (9)$$

where $[O_3]$ represents surface O_3 concentrations, R_a (s m^{-1}) stands for aerodynamic resistance, which expresses turbulent transport efficiency in transferring sensible heat and water vapor between the land surface and a reference height. The constant k_{O3}=1.67 is the ratio of stomatal resistance for O_3, estimated based on the theoretical stomatal resistance to water (Laisk et al., 1989). When plants are exposed to $[O_3]$ (Eq. 9), A_{tot} and g_s will decrease (Eq. 6 and Eq. 7) if the excess O_3 enters leaves (Eq. 8). The increased stomatal resistance acts to protect plants by reducing the O_3 uptake of stomata. Consequently, the damage scheme describes both changes in photosynthetic rate and stomatal conductance." (Lines 161-169)

2.3 Experiments

Line 139: "two sets of simulations" are mentioned. Does it mean that each experiment contains more than one run, or that it's just "two simulations" (one run for each of the experiments)?

Response:

Corrected. It is "two simulations". (Lines 172)

Line 140-142: the simulation labels meaning could be made explicit.

Response:

Thank you for the suggestion. We changed the experiment names as follow: "The control experiment "O3_offline" was conducted without the O_3 damages to vegetation. As a comparison, the sensitivity experiment "O3_online" contained online O_3-vegetation interaction with high O_3 sensitivity." (Lines 173-175)

Line 142: please be more explicit with "high O_3 sensitivity".

Response:

Thank you for the suggestion, we provided more explanations as follow in Section 2.2: "a_h (mmol m^{-2} s^{-1}) is the high O_3 sensitivity coefficient, calibrated by Sitch et al. (2007) on data from field observations by Karlsson et al. (2004) and Pleijel et al. (2004) to represent 'high' sensitivity of relative species of each PFT." (Lines 156-158)

2.4 Data for evaluations

I'd include in this section how each variable is evaluated specifically, at least when the evaluation is different than what expected – for instance, the evaluation carried out later refers to the surface daily maximum 8-hour ozone, whereas I expected ozone to be evaluated at the same time resolution of the model (or at least over a temporal scale that is more related to ozone vegetation fluxes). However, in general, specifying the temporal resolution of the dataset used for evaluation might help clarifying things.

Response:

We focused our validation efforts on the MDA8 O_3 variable, as O_3-vegetation interactions primarily occur during the daytime and our model can output monthly averaged MDA8 O_3 results.

Line 161: which simulation are you evaluating? It is not clear.

Response:

Clarified as follow:

"We evaluated the simulated air pollutants, carbon fluxes, and meteorological variables from 'O3_offline' run using observational and reanalysis datasets." (Lines 197-198)

Line 165-167: Was there any reason for picking the years 2009-2011, as opposite to including more years? Since the simulations you're using cover 10 years, it might be more adequate to compare them with more years.

Response:

The simulations in this study each run for 30 years, with the first 10 years dedicated to spin-up. Our primary focus is on the average data from the final 20 years, centered around 2010. In other words, using the average of observations from 2009 to 2011 is sufficient for model evaluation. However, in the revised version, we addressed this concern by using the period from 2005 to 2014 for validating the observed variables, except for GPP from Jung et al., (2011), for which only the latest data until 2011 were available. Given that the results indicate little variation in the evaluation effect between these two time periods, we did not change GPP observational data with longer time series.

"The worldwide observations of the maximum daily 8-hour average O_3 (MDA8 O_3) concentrations were mainly collected from three regional networks: Air Quality Monitoring Network operated by Ministry of Ecology and Environment (AQMN-MEE) in China, the Clean Air Status and Trends Network (CASTNET) in the U.S., and the European Monitoring and Evaluation Programme (EMEP) in Europe. Observations used for validation beyond China, sourced from Sofen et al. (2016), are averaged over the period 2005-2014. This dataset encompasses 7288 station records worldwide and excludes the uncertainty associated with high mountain-top sites. For AQMN-MEE, the mean value of 2014-2018 was used due to its establishment in 2013. The simulated aerosol optical depth (AOD) and LAI were validated using satellite-based data from the Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals collection 5 (Remer et al., 2005) (http://modis.gsfc.nasa.gov/) averaged for the years 2005-2014. The simulated GPP was evaluated against the data product upscaled from the FLUXNET eddy covariance measurements for 2009-2011 (Jung et al., 2011). The daily temperature at 2m (T_{2m}) in 2005-2014 was obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis 1 (NCEP1) (Kalnay et al., 1996). For precipitation, we used the monthly data averaged in 2005-2014 from Global Precipitation Climatology Project (GPCP) (Huffman et al., 1997; Adler et al., 2018)." (Lines 198-217)

Line 170-171: could you be more specific about this data product? What do you mean by upscaled?

Response:

The "upscale" refers to the process of extrapolating or extending localized GPP datasets derived from eddy covariance measurements to a larger spatial scale. This involves using machine learning algorithms to scale up the observations from FLUXNET tower networks to generate global estimates of carbon and water fluxes in the study of Jung et al. (2011). We revised this sentence as follows:

“The simulated GPP was evaluated against the data product upscaled from the FLUXNET eddy covariance measurements for 2009-2011 (Jung et al., 2011).” (Lines 211-212)

Line 177-179: I believe NMB to be useful when comparing different quantities, but the non-normalized mean bias might convey a better quantification for some variables (such as ozone, or temperature), and I’d advocate for it either in place or siding the normalized version (for instance substituting the map of the observed data with the map of the non-normalized mean bias).

Response:

Thank you for the suggestion. We showed both normalized mean bias (NMB) and root mean square error (RMSE) in the revised paper:

“Root-mean-square-error (RMSE) and normalized mean biases (NMBs) were applied to quantify the deviations of simulations from observations:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2} \quad (10)$$

$$NMB = \sum_{i=1}^{n}(S_i - O_i) / \sum_{i=1}^{n} O_i \times 100\% \quad (11)$$

Here, S_i and O_i represent the simulated and observed values, respectively. *n* denotes the total grid number used in the comparisons.” (Lines 218-223)

We also replaced the scatter plots with the mean differences between simulations and observations in the validations. Please notice the slight changes in statistical metrics (such as r, NMB) due to the changes in the selected validation period.

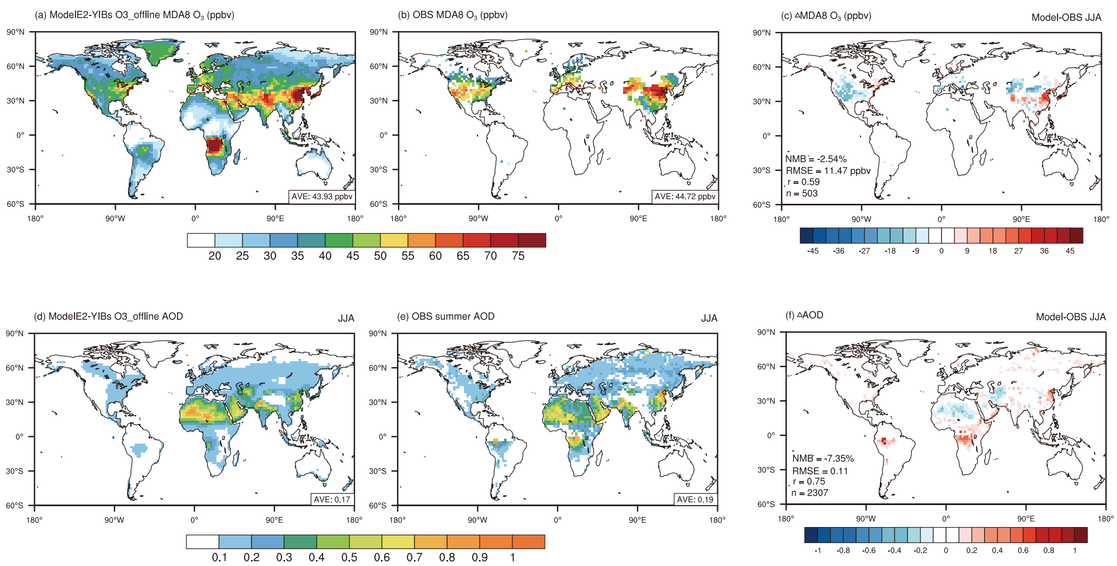


Figure 1. Evaluation of the boreal summertime (June-August) air pollutants at the present day simulated by the ModelE2-YIBs model. Surface daily maximum 8-hour ozone (MDA8 O_3; a-c) and aerosol optical depth (AOD; d-f) from the simulation O3_offline (a & d) and observations (b & e) are compared. The correlation coefficients (r), root mean square error (RMSE), normalized mean bias (NMB), and number of grid cells (n) for the comparisons are listed on the mean bias maps (c & f).

Results

3.1 Model evaluations

I believe that claiming a certain evaluation metric (such as correlation or NMB) to be high or low, or a certain variable to be adequately replicated, is a loose statement when not framed contextually. Any statement regarding the quality of an evaluation should reference a specific context. For instance, specifying if the evaluation is good compared to the literature, if the evaluated variable is the best among the ones being evaluated, or if the quality of the simulated variable meets the needs of the study. Furthermore, any proposition in this regard should be adequately motivated. If it is not possible to do so, I suggest leaving the numerical evaluation, without any qualitative remark. I signaled in the specific comments which are the lines that I found improper.

Response:

Thank you for your suggestion. We kept only the numerical assessment in the revised section and removed the qualitative description.

I think that this section does not cover strictly model evaluation, but also describes and contextualizes variables, so a different title might be more appropriate.

Response:

We changed the title to: "**3.1 The control simulation and model evaluations**". (Line 226)

Please be more specific as to which simulation you are evaluating. As far as I understand, it is "10NO3", but it should be made explicit throughout the text.

Response:

Clarified as follow:

"We first evaluated the air pollutants simulated by the control simulation O3_offline of ModelE2-YIBs model (Fig. 1)." (Lines 227-228)

“Simulated AOD at 550 nm by O3_offline (Fig. 1d) showed similar spatial pattern as the satellite retrievals (Fig. 1e) with R=0.75 and NMB of -7.35% globally (Fig. 1f).” (Lines 238-240)

“We then evaluated the simulated GPP and LAI by the control experiment for the boreal summer period (Fig. 2).” (Lines 243-244)

“We further validated the simulated meteorology from O3_offline (Fig. S2).” (Line 254)

Line 186: “adequately” (see general comment)

Response:

Deleted as suggested.

Line 191-192: Is this referred to the MDA8 average? Or just concentration averages? It would be better to refer always to the same quantity.

Response:

Sorry for the confusion, we changed the abbreviation ‘[O_3]’ to ‘MDA8 O_3’.

“Over a total of 503 grids with site-level O_3 measurements (Fig. 1b), the model replicated both the magnitude and spatial distribution of MDA8 O_3, with correlation coefficient (r) of 0.59 and NMB of -2.54% (Fig. 1c). Simulated summertime surface MDA8 O_3 was high in regions with large anthropogenic emissions, such as western Europe and eastern China (Ohara et al., 2007), as well as in central Africa with frequent fire emissions (van der Werf et al., 2017). On the global scale, the model yielded an average MDA8 O_3 of 43.93 ppbv and observations showed an average of 44.72 ppbv over the same grids.” (Lines 228-235)

Line 195: “high R=0.77 and low NMB of -6.27%” (see general comment)

Response:

We revised the observational datasets from the period 2009-2011 to 2005-2014. Consequently, the relative correlation and NMB values may change for certain variables. Revised as follows:

“Simulated AOD at 550 nm by O3_offline (Fig. 1d) showed similar spatial pattern as the satellite retrievals (Fig. 1e) with R=0.75 and NMB of -7.35% globally (Fig. 1f).” (Lines 238-240)

Line 211: "low NMB of 8.49%" (see general comment)

Response:

Revised as follows:

"For surface air temperature, the model (Fig. S2a) reproduced observed (Fig. S2b) pattern with RMSE of 3.21 °C and r of 0.99 against observations (Fig. S2c)." (Lines 254-256)

Line 212-213: both simulations are referred to, but there's only one NMB value, and one correlation value, and the figure refers only to one of the simulations (10NO3).

Response:

We are sorry for the confusion. Here the word 'both' referred to 'simulations and observations' instead of 'two simulations'. We removed it and clarified as follows: "For precipitation, the simulation (Fig. S2d) captures the observed spatial pattern (Fig. S2e) with NMB = 17.26% and r = 0.75 (Fig. S2f)." (Lines 256-258)

Line 213: could you provide any context to "high values in the tropical oceans"?

Response:

Sorry for the confusion. The main point we want to emphasize is that the model well captures the spatial distribution of precipitation. We removed this sentence in the revised paper.

Line 214-217: How do you define good performances? (see general comment)

Response:

Revised as follows:

"Overall, the model captures the spatial characteristics and magnitudes of air pollutants, biospheric parameters, and meteorological fields, making it a valuable tool for studying O_3-vegetation interactions." (Lines 258-260)

3.2 O_3 damage to terrestrial ecosystems

In this section, I would mention the fact that there are some areas of the globe that display higher GPP/stomatal conductance/LAI under "10HO3".

Response:

If only the effect of O_3 on vegetation (offline effect) is considered, GPP is negatively impacted on a global scale, with damage of -0.17 Pg[C] (-24.98%) and -0.52 Pg[C] (-16.71%) in eastern China and the eastern US, respectively (Fig. R3). Considering the feedback of O_3-vegetation interactions, the climate system is influenced and adjusted, resulting in both positive and negative impacts on ecosystem-related variables. Similar responses have been achieved in previous studies considering online O_3 vegetation damages (e.g., Sadiq et al., 2017). Overall, most of these positive changes are not statistically significant, especially when the confidence level is set to 95% (Fig. R4). And the changes in GPP due to O_3-vegetation interactions, primarily caused by O_3 damage on a global scale, predominantly show negative values, consistent with the spatial pattern observed in offline effect. We revised this section as follow to make the description clarified:

"We assessed the damaging effects of surface O_3 to ecosystems due to online O_3-vegetation interactions (Fig. 3)." (Lines 263-264)

"Though there are positive responses in some regions, they are not dominant and hardly significant." (Lines 273-274)

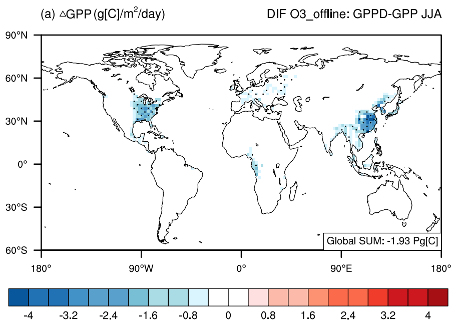


Figure R3. O_3-induced summer-time GPP loss simulated by the 'O3_offline' run.

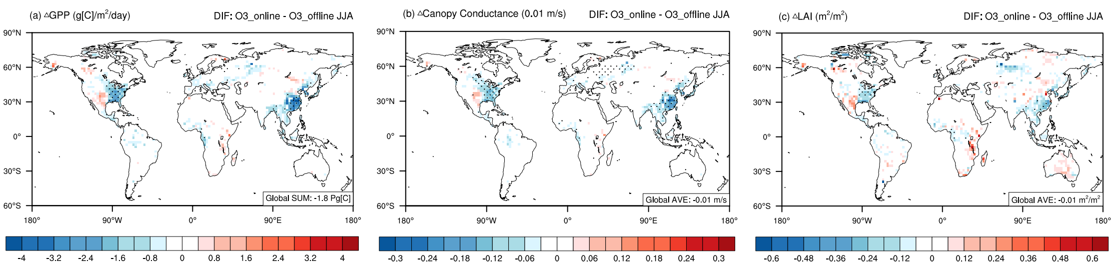


Figure R4. Same as fig. 3 but for significant changes with $p < 0.05$.

3.3 Global climatic responses to O_3-vegetation interactions

Line 249: could you be more specific about surface temperature? It is not clear what you're referring to, since it is then compared it with canopy temperature (line 251). I'd be more explicit.

Response:

Sorry for the confusion. In the new version, we've revised all the temperature-related variables to make them clearer. In this paper, the 'surface temperature' (Fig. 4a & Fig. S2a) refers to 'surface air temperature'. Here, we compare the increase in canopy temperature due to O_3-vegetation interactions observed in previous studies with the changes in surface air temperature simulated by our model. This comparison is valid because surface air temperature encompasses both vegetated and non-vegetated areas.

"Meanwhile, the reduction of latent heat flux promotes surface air temperature (Fig. 4a), resulting in the increase of sensible heat flux (Fig. 4f). Such warming was also reported in field experiments, where relatively high O_3 exposure resulted in noticeable increases of canopy temperature along with reductions of transpiration (Bernacchi et al., 2011; VanLoocke et al., 2012)." (Lines 293-298)

3.4 Changes of air pollution by O_3 -vegetation interactions

Line 285-286: "The enhancement of O_3 concentrations in polluted regions may exacerbate the warming effect of O_3 and cause additional damages to vegetation." Should be elaborated further.

Response:

Thank you for your suggestion, we elaborated further as follows:

"The enhancement of O_3 concentrations in polluted regions may exacerbate the warming effect of O_3 as a greenhouse gas and cause additional damages to vegetation. For instance, offline O_3 damages on GPP in eastern China and the eastern US are -0.52±0.03 Pg[C] (-24.98±0.91%) and -0.17±0.02 Pg[C] (-16.71±1.16%), respectively, smaller than those induced by O_3-vegetation interactions (Table S2)." (Lines 332-337)

Line 296-297: there's a citation of the paper title instead of the authors.

Response:

Corrected.

Conclusions and discussion

Should it be "Discussion and conclusions?"

Response:

Revised as suggested.

Line 310: Does "surface warming" refers to air surface temperature?

Response:

Yes, it refers to the increase of surface air temperature.

Line 312: At first glance, the word "further" seems contradictory with the previous statements. For instance, I would suggest replacing the sentence with "However, the enhancement of cloudiness decreased surface temperature…". Ultimately, just from this sentence, it is unclear if the net effect is an increase or decrease in air temperature, or if these contrasting effects involve different regions.

Response:

Revised as suggested:

"However, the enhancement of cloudiness decreased surface temperature and promoted precipitation outside the key regions with intense O_3-vegetation interactions." (Lines 361-363)

Line 326: Does "surface warming" refers to air surface temperature?

Response:

Yes, it is.

Line 327-328: Would you be able to provide any explanation for this difference.

Response:

Revised as follow:

"The magnitude of these responses was much stronger than our predictions, likely because they considered the accumulation effect of O_3." (Lines 377-378)

Line 352-354: I suggest being more specific.

Response:

The differences between these works are discussed in details in the above context.

"For example, the simulations by Lombardozzi et al. (2015) revealed that surface O_3 reduces global GPP by 8%-12% and transpiration by 2-2.4% with regional reductions up to 20% for GPP and 15% for transpiration in eastern China and U.S. These changes were in general consistent with our results though we predicted larger reductions in transpiration than GPP due to O_3-vegetation interactions. Using the same scheme as Lombardozzi et al. (2015), Sadiq et al. (2017) showed that O_3-vegetation coupling induced the surface warming of 0.5-1^{o}C and O_3 enhancement of 4-6 ppbv in eastern China and eastern U.S. The magnitude of these responses was much stronger than our predictions, likely because they considered the accumulation effect of O_3." (Lines 370-378)

Line 356-357: Most readers would recognize that a coarse resolution would be a limitation, but I would be more specific as to why with respect to O_3-vegetation interaction. For instance, later (line 360), it is mentioned that high-resolution improves simulation for extreme events: are extreme events relevant for O_3-vegetation interactions?

Response:

Severe O_3 pollution can occur under extreme conditions such as heat waves and droughts. Lin et al. (2020) found that during drought events, the O_3 removal capacity of water-stressed vegetation decreases, exacerbating severe O_3 pollution. Mills et al. (2016) noted that both extreme temperature and O_3 have impacts on critical growth stages of plants. We revised the related context as follow:

"However, high-resolution models exhibit improved simulations of extreme events (Chang et al., 2020; Ban et al., 2021), which have certain effect on O_3-vegetation interactions (Mills et al., 2016; Lin et al., 2020)." (Lines 408-410)

Line 357-359: this sentence is unclear – it seems like "Ito et al. (2020) shows… that the model results are involved in the CMIP6 Coupled Climate-Carbon Cycle MIP (C4MIP)", as if being included in the CMIP6 guarantees by itself that carbon fluxes are well represented.

Response:

We removed this sentence in the revised paper for the better clarity.

Figures

Figure 1: there's a mistake in the panel letters.

Response:

Corrected.

Figure 1-2: it might be more useful to show the mean bias maps instead of the observed values, as it allows for easier comparisons.

Response:

Revised as suggested:

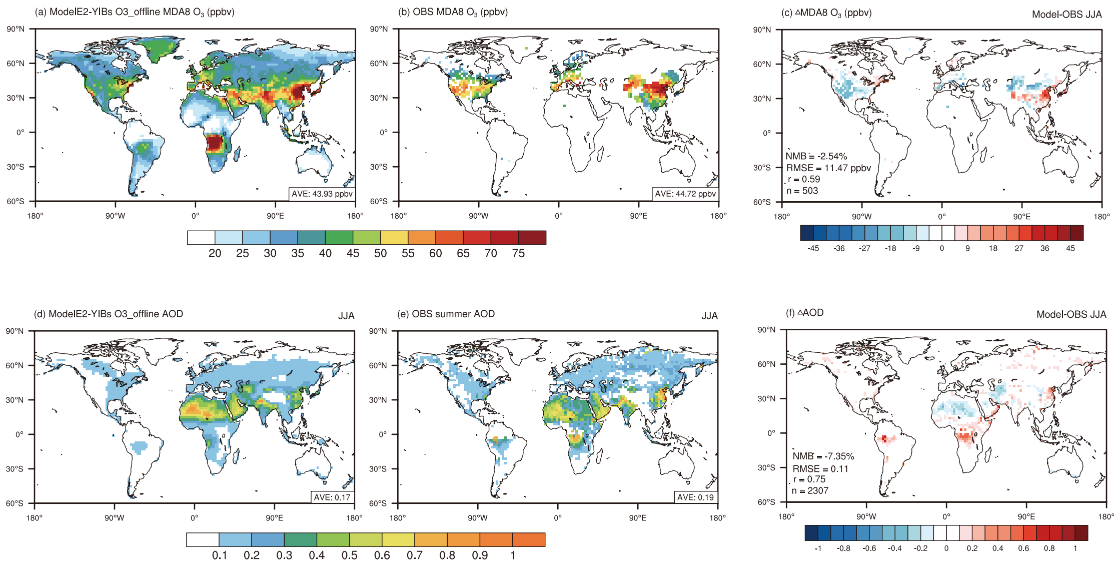


Figure 1. Evaluation of the boreal summertime (June-August) air pollutants at the present day simulated by the ModelE2-YIBs model. Surface daily maximum 8-hour ozone (MDA8 O_3; a-c) and aerosol optical depth (AOD; d-f) from the simulation O3_offline (a & d) and observations (b & e) are compared. The correlation coefficients (r), root mean square error (RMSE), normalized mean bias (NMB), and number of grid cells (n) for the comparisons are listed on the mean bias maps (c & f).

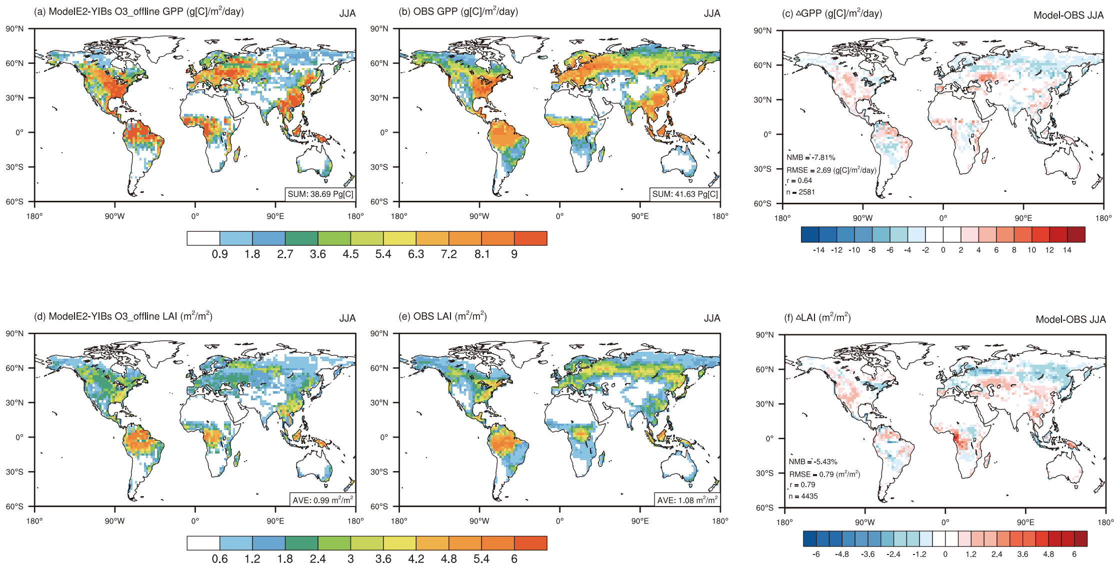


Figure 2. The same as Fig.1 but for gross primary productivity (GPP; a-c) and leaf area index (LAI; d-f).

Figure 3: have the p-values been corrected to account for the multiple repetitions in space in some ways? For instance, with Bonferroni, or false discovery rate.

Response:

No, we used the standard 't-test' function.

Figure 4a: you refer to this as "air surface temperature" in the text (line 241), but here you call it "Tsurf", which I think generates confusion with land surface temperature.

Response:

We revised the figure titles as follow:

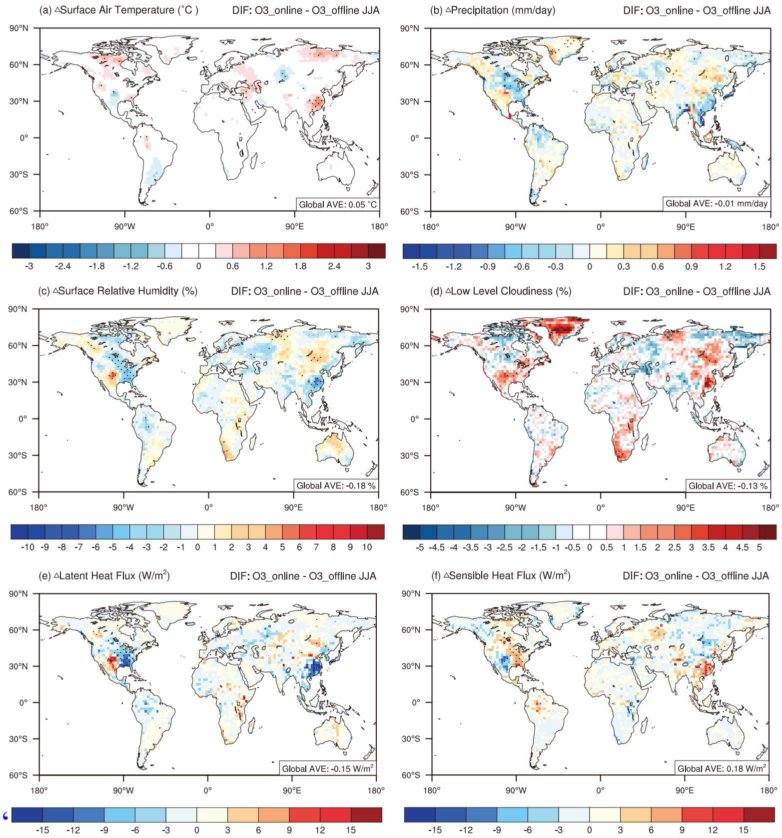
“

Figure 4. Changes of boreal summertime meteorological fields by O_3-vegetation interactions at the present day. Results shown are changes of (a) surface air temperature, (b) precipitation, (c) surface relative humidity, (d) low level cloudiness, (e) latent heat flux, and (f) sensible heat flux between simulations O3_online and O3_offline. For heat fluxes, positive values (shaded in red color) indicate the upward fluxes change. Black dots denote areas with significant changes ($p < 0.1$)."

Figure 3, 4, 6: I believe that the sentence "Please notice the differences in the color scales" is redundant when comparing quantities with different unit of measurement.

Response:

We deleted these sentences in the revised version.

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